Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 8 (2011) 421–426

Energy Procedia

SiliconPV: 17-20 April 2011, Freiburg, Germany

Results on n-type IBC solar cells using industrial optimized techniques in the fabrication processing

G. Galbiati , V. D. Mihailetchi , A. Halm , R. Roescu , R. Kopecek

International Solar Energy Research Center - ISC Konstanz, Rudolf-Diesel Str.15 , D-78467 Konstanz, Germany

Abstract

Back-contact back-junction solar cell has the potential for high efficiency energy conversion due to the distinctive architecture of the device. The fabrication processing for these types of cells requires high material quality and complicated processing technology involving many masking and alignments steps which results in the increase of the manufacturing costs. Within the LIMA EU Project, we developed a novel process architecture for Interdigited-Back-Contact (IBC) front surface field (FSF) solar cells obtained by optimization of the fabrication process using only industrially feasible technology (i.e. screen-printing, laser ablation and conventional diffusion processes). With this process we have obtained cell efficiencies above 19% on n-type silicon 2x2 cm^2 float zone (FZ) substrate. Moreover, we have integrated this process with innovative methodology which opens new possible solution to the already well established techniques. This approach allowed us to improve the front side with excellent proprieties of passivation and conductivity and to implement interdigitated phosphorous back surface field (BSF) and boron emitter in a single mask process. The solar cells results of this improved front side are presented in comparison to the solar cells with IBC-FSF architecture.

Selection and/or peer-review under responsibility of SiliconPV 2011

Keywords: Interdigitated back contact solar cell; n-type;

1876–6102 © 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of SiliconPV 2011.
Open access under CC BY-NC-ND license. doi:10.1016/j.egypro.2011.06.160

1. Introduction

Interdigitated back contact (IBC) solar cells are becoming more attractive for the industry due to their potential of driving down the cost of the solar energy by increasing the amount of power generated by each solar panel. Another considerable advantage is given by the reduced complexity of cell interconnection inside the module. Among the high efficiency solar cells, IBC cells, by their simplification can reach the key-solution for the dilemma of cost versus efficiency. N-type IBC silicon solar cells have been successfully applied in the production with high efficiencies up to 24,2% by SunPower Corp. [1] and are actually investigated by several research groups. The advantages of this architecture are in part overshadowed by the relative high production cost; indeed both doped regions and contacts are placed on the same side of the cell, thus many masking steps and alignments are necessary to realize the back-contact and back-junction features.

Within the LIMA EU project, ISC-Konstanz developed a screen-printing approach to simplify the IBC solar cells fabrication. The target of the LIMA project is to improve the light interaction with the silicon material in order to overcome the low absorption coefficient due to its indirect bandgap. The EU LIMA consortium is working on three complementary perspectives: nanostructured active layer, nanostructured plasmonic layer and the resulting novel cell geometry. The role of ISC-Konstanz in the LIMA project is mainly to design and fabricate the IBC cells concept taking into account several aspects related to the industrial application and technical feasibility of the devices. Indeed our aim is to develop an industrial process starting from conventional technologies currently available in the solar cell manufacture lines. Moreover, we have upgraded this process with innovative methodology which opens new possible solution to already well established techniques. This approach (improved front surface) allowed us to optimize the front side with excellent proprieties of passivation and conductivity as well as to implement the interdigitated phosphorous back surface field (BSF) and boron emitter in a single mask process.

Different pitch sizes ranging from 1 mm to 3.5 mm with an emitter fraction in the range of 50% to 86% are tested. Efficiencies above 19% under 1 Sun illumination on IBC solar cells with an active area of 2x2 cm^2 have been achieved on 10-15Ωcm n-type FZ silicon for both FSF-architecture and the improved front surface structure. In particular, the latter one is very appealing due to its current output over all the pitch sizes and for its potential further optimization.

1.1. Solar cell process

The solar cells used in this study were fabricated on 160µm thick n-type FZ silicon wafers with bulk resistivity of 10-13Ωcm. The front surface is textured with random pyramids in NaOH/isopropanol solution and passivated with a shallow phosphorus $n+$ front surface field (FSF) diffusion and covered by a PECVD SiN_x antireflection layer. The phosphorus back surface field (BSF) is obtained by $POCl_3$ diffusion and subsequently covered by SiN_x. The emitter pattern is defined by laser opening the mask layer and formed by BBr_3 diffusion. Finally a metal paste is screen-printed to create the back contacts. The flow-chart with the processing steps and the schematic cross-section of the obtained cell are presented in Fig. 1.

Starting from this architecture we developed an advanced front surface layer in order to enhance the conversion energy efficiency. The correct process sequence and the reliability of the process are still under investigation for a possible patent application.

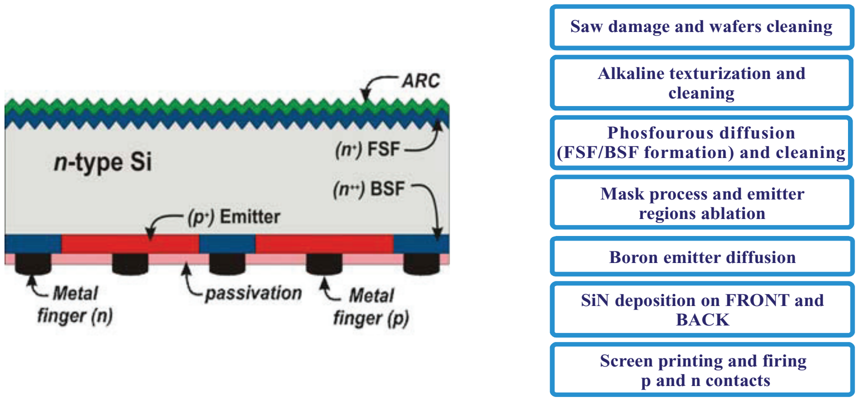

Fig. 1 (a) Cross section view of the FSF solar cell (b) Flow chart of the main fabrication process steps

1.2. Measurement stage

In order to asses the performance of our novel processes, the miniature IBC solar cells were characterized both with optical and electrical methods. For the electrical characterization we have used a specially designed chuck which can be integrated at different measurement facilities, as depicted in Fig. 2 (a). It allows to independently contacting each of the twenty three cells on the wafer into a four-probe configuration and its electronic controls give the possibility to switch between each of them in order to automatize the recording of the current-voltage (I-V) characteristics. The I-V measurements were performed with a Class A solar simulator at 25 deg C at 1 Sun AM1.5. The temperature was measured in the center of the wafer and supposed to be the same for all the cells as the thermal simulations under illumination shown almost no temperature gradient on the surface of the chuck. Slight non-uniformities (<2%) in the irradiance across the wafer were taken into account and compensated before extracting the cell parameters from the I-V curves. The values were consistent with results obtained by employing alternative characterization techniques (e.g. Suns Voc, spectral response). During the measurements, the front surface of the wafer was masked as in Fig. 2 (b) in order to prevent the photo-carrier generation in the semiconductor regions outside the actual solar cell being collected.

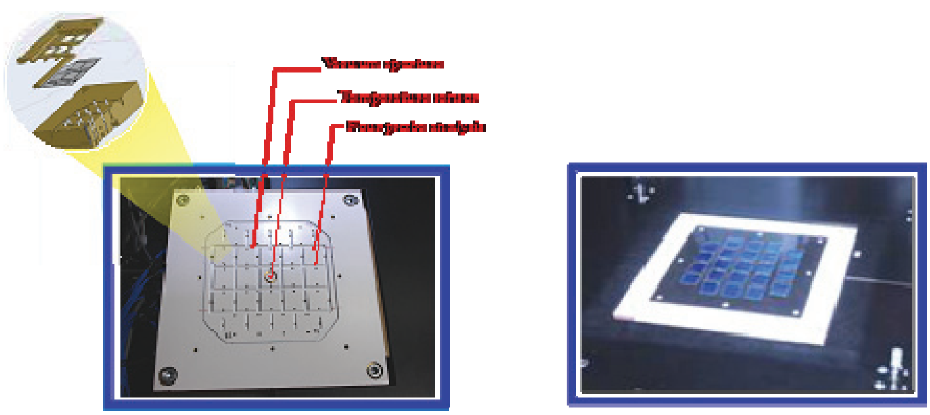

Fig. 2 (a) The measurement chuck for IBC-cells has been designed and assembled at ISC-Konstanz. Together with its electronics controls it allows to automatically switch the measurements between 23 solar cells in four-probe analysis at controlled temperature. The chuck was covered with a white diffusive paint in an attempt to mimic the conditions present inside a typical module. (b) Masked chuck during IV-measurement.

2. Result

Differently than in the photolithographic process, the application of low-cost technologies such as screen printing and laser techniques leads to loss of resolution and positioning accuracy. Moreover using low cost techniques results in the p-n pitch in the range of millimeters thus the majority carriers have to travel larger lateral distances before reaching the base contacts. Lateral transport of the majority carriers is causing significant series resistance losses.

In the second stage of our studies, we upgraded the FSF-IBC solar cells process with an innovative methodology which allows us to optimize the front side with excellent proprieties of passivation and conductivity as well as to implement interdigitated phosphorous BSF and boron emitter in a single mask process. The results and comparison with FSF show a large potential of application for this novel layer. In this work we present the output result for these two types of solar cells architectures.

As it is shown in Fig. 3 (a) the improved front structure allow to collect more current compare with the FSF-architecture. The difference is within 2-6% (rel.) depending on the pitch sizes. The FF trend is shown in Fig. 3 (b) where the influence of the FSF (blue line) limiting the drop in fill factor is clearly visible. The same behavior does not appear for the improved front surface architecture (red line); indeed for an emitter fraction larger than 70% a severe degradation in FF is obtained. It is important to observe the improvement in FF about 1.5% (rel. in average) for pitches below 1.4 mm. The trend between Jsc and FF yield an efficiency behavior shown in Fig. 4. The best electrical performance of these cells under AM1.5 illumination is given in Table-I. The top efficiency of 19.6% was achieved for the FSF-structures solar cells on 13Ωcm 2x2 cm^2 *n-type* FZ-Si with a pitch of 2.2 mm. The low FF is partially due to the high base resistivity that seriously harms the lateral conductivity. For both configurations close energy conversion efficiencies have been reached at different pitches. The best result for the FSF-structure at 2.2 mm pitch size is mainly due to the gain in FF while the higher efficiency for the improved front surface (η=19.4%) occurs at 1.4 mm pitch size.

These achieved results show room for further improvement considering the large detriment in FF factor implied by the high base resistivity Si-wafers used in this experiment. Indeed we believe that solar cells structured with the improved front surface architecture and made with highly doped silicon will result in a large improvement in current at the pitch value of 1.4mm. In this configuration the FF will also increase, allowing the energy conversion efficiency value above 20%.

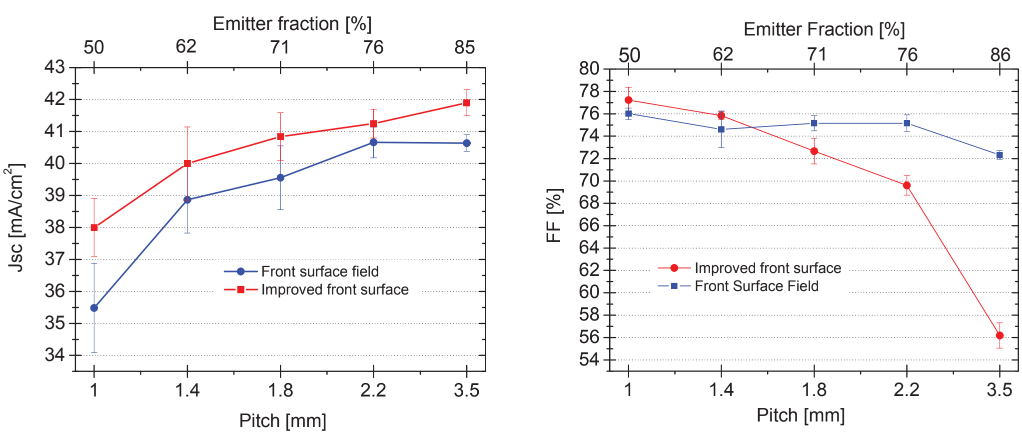

Fig. 3 Dependence of Jsc(a) and FF(b) on the pitch for FSF and improved front surface solar cells structures. A larger pitch with fixed base width results in a larger emitter fraction on the rear side. The solar cells have a pitch of 1, 1.4, 1.8, 2.2, and 3.5 mm where the base width was fixed at 500µm

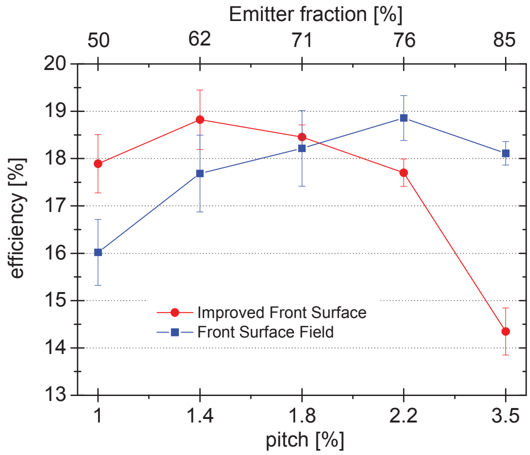

Fig. 4 Energy conversion efficiency for FSF and improved front surface architectures

Cells type	***Pitch [mm]***	***Jsc [mA/cm2]***	***Voc [mV]***	***FF [%]***	***eta [%]***
Front Surface Field (FSF)	2.2	41.3	624	75.9	19.6
Improved surface field	1.4	40.5	624	76.8	19.4

Table 1 Best results on n-type 10-13Ωcm FZ-Si IBC solar cells on active area of 2x2cm^2

The comparisons of the internal quantum efficiency (IQE) data are shown in Fig. 5 (a). In this case only the best cells for both architectures were measured. It is shown that both cells in their best pitch configuration reached the value of 100%-IQE. At short wavelength it is also possible to see the influence of the front side passivation which is not yet fully optimized. Moreover higher values at shorter and longer wavelengths reveal the potential of the improved front surface process.
In order to evaluate the shading losses due to the rear side recombination in the region of the base busbar and base finger a light beam induce current (LBIC) measuremant have been performed. Fig. 5 (b) shown IQE maps on 2x2 cm^2 solar cells. At 980 nm it is cleary visible the weaker signal over the base finger and busbar. Especially is remarkable the high output signal (IQE $\cong$ 0.9) at 405nm due to the high cunductivity proprieties of the front side for the improved front surface architecture.

3. Conclusion

As a part of the cost reduction strategy within the LIMA EU project, we fabricated 2x2cm^2 monocristalline high-efficiency silicon solar cells with back-contact, back-junction structure. The first result were obtained with a FSF structure cells with efficiency of 19.6% at pitch of 2.2 mm and emitter coverage of 76%. Moreover we developed an advanced front side that integrated in the FSF-IBC process cells leads to best efficiency of 19.4% at pitch of 1.4 mm and emitter coverage of 62%. The requirements on the accuracy of patterning have been reached by screen printing and lasers processing. The achievements presented in this paper show a great potential to reach an efficiency target above 20% when using the improved front surface architecture.

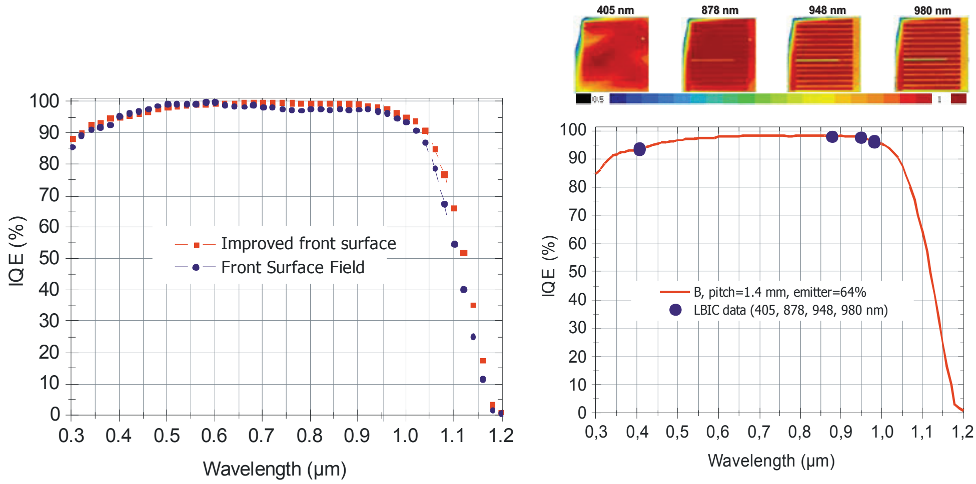

Fig. 5 (a) IQE data comparison between FSF and improved front surface cells structures. The increased values at short and long wavelengths for the improved surface architecture show the potential of this process. (b) IQE signal from LBIC map measurements at different wavelengths for the improved front surface structure. The optimized front side is responsible to reduce the electrical shading losses due to the base finger and busbars.

Acknowledgements

This work has been supported by the EU within the LIMA project under contract no. FP7-248909

References

[1] P. *Cousins, et* al., Proceedings of the *35th*. PVSEC hawaii, Honolulu, USA (2010)